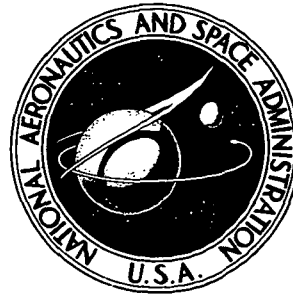


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A GENERALIZED THEORY  
FOR THE DESIGN OF  
CONTRACTION CONES AND  
OTHER LOW-SPEED DUCTS

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# A GENERALIZED THEORY FOR THE DESIGN OF CONTRACTION CONES AND OTHER LOW-SPEED DUCTS

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## SUMMARY

A generalization of the Tsien method of contraction-cone design is described. The design velocity distribution is expressed in such a form that the required high-order derivatives can be obtained by recursion rather than by numerical or analytic differentiation. The method is applicable to the design of diffusers and converging-diverging ducts as well as contraction cones. The computer program is described and a FORTRAN listing of the program is provided.

## INTRODUCTION

For incompressible flows in ducts of slowly varying radius the one-dimensional flow relation between the velocity and the cross-sectional area can be used to predict the velocity distribution in a given duct or to design a duct for a desired velocity distribution.

However certain applications, such as the contraction cone for a wind tunnel, require short ducts with a relatively rapid variation of the wall radius. For such applications the one-dimensional relation no longer suffices, and a solution of the differential equation of the flow must be sought. Tsien (ref. 1) derived a solution for the stream function in terms of a prescribed axial velocity distribution, and applied this solution in the design of a wind-tunnel contraction cone.

It should be mentioned that such a design, obtained from the incompressible-flow equations, is a conservative design in the sense that when it is operated at off-design compressible conditions, the ratio of exit velocity to entering velocity is higher than the design ratio.

The major difficulty in applying Tsien's solution arises from the stringent requirements on the form of the input axial velocity distribution. These requirements are such that only a small class of functions can be used to describe the design velocity distribution. This problem has been considered in reference 2, where a form of velocity distribution different from that of reference 1 is used.

This form allows more freedom in shaping the design velocity function, but it introduces the problem of requiring hand calculations in analytic form of many derivatives of the function. Other analyses have utilized different formulations of the solution of the differential equation according to the way the variables are separated in solving the equation. The method of reference 3 assigns an exponential type of variation in the axial direction, and so is limited to a single design velocity distribution. References 4 and 5 use a periodic axial velocity distribution, but inasmuch as the flow is not periodic, this formulation gives rise to errors near the beginning and the exit of the contraction cone. An additional problem with this latter method is that the finite-term trigonometric approximation to a function is in general a function that oscillates about the desired function, and such a "wavy" distribution is not very satisfactory for design purposes. The three forms of solution for the stream function are given explicitly in reference 5.

The present analysis represents a generalization of the method of reference 1, in that a wide range of design velocity distributions is permitted so that the method is no longer restricted to a specific contraction cone but may be applied to the design of a wide variety of ducts. Greater accuracy is obtained through the use of an electronic computer and by retaining a large number of terms in the series solution.

## SYMBOLS

$A, B, c, d_n$  arbitrary parameters and coefficients in expression for design velocity

$$f_d = f_g - f_p$$

$f_g$  general form of design velocity distribution at centerline

$f_p$  preliminary form of design velocity distribution at centerline (eq. (3))

$f_0$  design velocity distribution at centerline used in reference 1

$G$  total velocity

$H_n$  nth Hermite polynomial

$k$  upper summation index

$m, n$  indices

$x, r$  cylindrical coordinates

$u, v$  axial and radial velocity components, respectively

$z = cx$

$\delta_{mn}$  Kronecker delta

$$\Phi = \frac{c}{\sqrt{\pi}} e^{-c^2 x^2}$$

$\psi$  stream function

Subscripts:

$i$  initial

$f$  final

$m, n$  indices

## ANALYSIS

Tsien's solution (ref. 1) for the axial and radial velocities in incompressible axisymmetric flow is

$$u = \sum_{n=0}^{\infty} \frac{(-1)^n f_0^{(2n)}(x) r^{2n}}{2^{2n} (n!)^2}$$

$$v = \sum_{n=1}^{\infty} \frac{(-1)^n 2nr^{2n-1} f_0^{(2n-1)}(x)}{2^{2n} (n!)^2}$$

where  $f_0(x)$  is the prescribed velocity on the axis. The stream function can be obtained by integration. Its  $k$ -term approximation is

$$\psi = \sum_{n=1}^k \frac{(-1)^{n-1} f_0^{(2n-2)}(x) r^{2n}}{2^{2n-1} n [(n-1)!]^2} \quad (1)$$

The kind of functions  $f_0(x)$  which are appropriate for describing the axial velocity distribution will now be examined. It is apparent that if the series is truncated at the

nth term  $2n - 2$  derivatives of  $f_0$  are required. Therefore,  $f_0$  must be such that these derivatives can be obtained in analytic form because it is generally impossible to obtain high-order derivatives numerically with accuracy. Furthermore, as has been pointed out in reference 2, the simplest way to insure that conditions at infinity upstream and downstream be uniform is to require that all the derivatives of  $f_0$  vanish as  $x \rightarrow \pm\infty$ , but of course  $f_0$  must not itself vanish at  $x = \pm\infty$ .

Thus it is seen that the class of functions that can be used to describe the axial velocity is severely limited.

In reference 1 this velocity distribution is prescribed by the function

$$u_{r=0}(x) = f_0(x) = 0.55 + \frac{0.9}{\sqrt{2\pi}} \int_0^x e^{-\frac{x^2}{2}} dx \quad (2)$$

The following analysis generalizes the procedure of reference 1 so that a much larger variety of design velocity distributions is permitted and in such a way that the series can be carried out to an arbitrary number of terms without any penalty except a trivial increase in machine computing time.

The basic preliminary form of the design velocity function is chosen to be

$$f_p(x) = A + \frac{2cB}{\sqrt{\pi}} \int_0^x e^{-c^2x^2} dx \quad (3)$$

which is only a slight generalization of equation (2). The derivatives of this expression can be obtained by recursion, following a development similar to that of reference 1: Let

$$\Phi(x) = \frac{c}{\sqrt{\pi}} e^{-c^2x^2}$$

then the  $m + 1$  derivative of  $f_p$  is

$$f_p^{(m+1)}(x) = 2B \Phi^{(m)}(x)$$

Substitute

$$\left. \begin{aligned} x &= \frac{z}{c} \\ z^2 &= c^2x^2 \end{aligned} \right\} \quad (4)$$

then

$$\Phi^{(m)}(x) = \frac{c}{\sqrt{\pi}} c^m \frac{d^m}{dz^m} e^{-z^2} = \frac{c^{m+1}}{\sqrt{\pi}} (-1)^m e^{-z^2} H_m(z)$$

or

$$\Phi^{(m)}(x) = (-1)^m c^m \Phi(x) H_m(z) \quad (5)$$

where  $H_m(z)$  is the  $m$ th Hermite polynomial (see eq. (29) on p. 91 of ref. 6). The recurrence formula for Hermite polynomials is

$$H_m(z) = 2z H_{m-1}(z) - 2(m-1) H_{m-2}(z)$$

Multiply both sides by  $(-1)^m c^m \Phi(x)$  and then equation (5) becomes

$$\begin{aligned} \Phi^{(m)}(x) &= 2z(-1)^m c^m H_{m-1}(z) - 2(m-1)(-1)^m c^m H_{m-2}(z) \\ &= -2c^2 \left[ (-1)^{m-1} \frac{z}{c} c^{m-1} H_{m-1}(z) + (m-1)(-1)^{m-2} c^{m-2} H_{m-2}(z) \right] \\ &= -2c^2 \left[ x \Phi^{(m-1)}(x) + (m-1) \Phi^{(m-2)}(x) \right] \end{aligned}$$

which is the desired recurrence formula for the derivatives.

Now consider a more general design velocity function  $f_g(x)$ , obtained by adding terms to  $f_p(x)$ . Since the initial and final velocities are determined by the coefficients in  $f_p(x)$ , these additional terms and all their derivatives must vanish at  $\pm\infty$ . They should also be such that an arbitrary number of differentiations can be performed analytically in a simple manner. These conditions are satisfied by the form:

$$f_g(x) = f_p(x) + \sum_0^k d_n e^{-x^2} H_n(x) \quad (6)$$

The factor  $e^{-x^2}$  in each term of the series assures that the conditions at  $\pm\infty$  will not be affected. The derivatives of these terms are obtained by the recurrence formula:

$$\frac{d}{dx} \left[ e^{-x^2} H_n(x) \right] = -e^{-x^2} H_{n+1}(x)$$

(ref. 7, p. 786, where the stated formula contains an extraneous factor of 2).

The coefficients  $d_n$  can be determined as follows by means of the orthogonality property of the Hermite polynomials. Denoting

$$f_d(x) = f_g(x) - f_p(x)$$

and substituting in equation (6)

$$f_d(x) = \sum_{n=0}^k d_n e^{-x^2} H_n(x) \quad (7)$$

multiplying by  $H_m(x)$  and integrating, yields

$$\int_{-\infty}^{\infty} f_d(x) H_m(x) dx = \sum_{n=0}^k d_n \int_{-\infty}^{\infty} e^{-x^2} H_n(x) H_m(x) dx = \sum_{n=0}^k \delta_{mn} 2^n n! \sqrt{\pi} d_n$$

Thus

$$d_m = \frac{1}{2^m m! \sqrt{\pi}} \int_{-\infty}^{\infty} f_d(x) H_m(x) dx$$

where the finiteness of the integral is assured by the nature of  $f_d(x)$ . Of course the series in equation (7) will, in general, only approximate  $f_d(x)$  since only  $k$  terms are used.

A simpler, but less accurate, approximation could be obtained by matching the function  $f_d(x)$  at  $k$  points and obtaining the coefficients as solutions of  $k$  simultaneous linear equations.

Actually, neither of these methods for determining the coefficients has been used so far. Rather, the calculation of  $f_g(x)$  was programed for visual display, and various values of the coefficients were tried until a close approximation to the desired  $f_g(x)$  was obtained.

A description and listing of the computer program is given in the appendix.

## DESIGN PROCEDURE

The basic considerations that govern the design of a contraction cone from a prescribed axial velocity distribution have been discussed in reference 2. In general the same considerations are applicable to the design of other kinds of ducts.

After selecting an appropriate axial velocity function the next step in the procedure is to determine several streamlines by solving the equation for the stream function,

$$\psi = \sum_{n=1}^k \frac{(-1)^{n-1} f_g^{(2n-2)}(x) r^{2n}}{2^{2n-1} n! [(n-1)!]^2}$$



where

$$f_g(x) = A + \frac{2cB}{\sqrt{\pi}} \int_0^x e^{-c^2 x^2} dx + \sum_{n=0}^k d_n e^{-x^2} H_n(x) \quad (8)$$

for  $r$  at the designated  $x$ -stations with fixed values of  $\psi$ . A computer program library routine, utilizing interval-halving, was used for this purpose. It may be noted that, in accordance with Descartes's rule of signs, there may be as many as  $k$  positive solutions of equation (1) for  $r^2$  and so for  $r$  (for fixed  $\psi$  and  $x$ ). However, any possible ambiguity in the solution can be avoided by making an initial estimate of the radius from the one-dimensional approximate relation between velocity and area ratio, after one point on the streamline has been computed.

As successive streamlines are determined, the velocity distributions along the streamlines are also computed. These display a greater radial variation in regions of larger curvature, eventually leading to an adverse velocity gradient in regions of inward turning of the wall. Of course some radial velocity gradient is normally acceptable, and generally a slight adverse velocity gradient can be tolerated by the boundary layer. These factors must be considered when selecting a streamline for the actual duct contour inasmuch as the duct length is shortened by taking larger values of the stream function. Since a short duct implies savings in material, space, and wall-friction losses, the usual design goal is to have the shortest possible duct compatible with acceptable flow quality.

## DISCUSSION AND EXAMPLES

The form of the design velocity distribution is determined by the choice of the various parameters in equation (8) in a manner which can be readily demonstrated. Using the identity  $\int_0^\infty e^{-c^2 x^2} dx = \frac{\sqrt{\pi}}{2c}$ , one readily computes that upstream, at  $x = -\infty$ ,

$$f_{g,i} = A - B$$

and downstream, at  $x = +\infty$ ,

$$f_{g,f} = A + B$$

Consequently  $A = \frac{1}{2}(f_{g,i} + f_{g,f})$ , the average of the initial and final velocities, and  $B = \frac{1}{2}(f_{g,f} - f_{g,i})$ . When  $d_n = 0$  for all  $n$  the velocity is  $A$  at  $x = 0$ ; and, inasmuch as the odd-order Hermite polynomials are odd functions of  $x$ , the presence of the terms containing these polynomials does not change the velocity at the origin. The even-order

polynomials, on the other hand, influence the velocity function in a symmetric (even) manner and, consequently, affect the velocity at the origin.

The nature of the exponential factor  $e^{-c^2x^2}$  in the integral term of  $f_g(x)$  and  $f_p(x)$  assures that  $f_p(x)$  will be essentially flat outside of some neighborhood of  $x = 0$ . Inasmuch as the terms of the summation each contain a factor of  $e^{-x^2}$ , the neighborhood of  $x = 0$  over which these terms alter  $f_p(x)$  depends on the magnitude of  $c$  compared to 1.

An example is shown in figure 1. Here an axial velocity distribution obtained by using only the two terms of  $f_p(x)$  (eq. (3)) is compared with one obtained with the same values for the parameters except with  $d_1 = 0.1$ . Thus, the initial and final velocities and the velocity at the origin are all unchanged, but the variation of velocity throughout the design region is radically changed. This distribution (with  $d_1 = 0.1$ ) has appropriate characteristics for a contraction-cone design, that is, it is relatively short between the flat ends with smoothly varying curvature. Figure 2 shows a contraction cone designed from this velocity distribution together with several internal streamlines. Figure 3 shows the distributions of velocity along these streamlines. As expected the radial variation of velocity is greatest near the entrance where the curvature is greatest.

A different kind of design velocity distribution is shown in figure 4. Here the initial and final velocities were prescribed to be 0.5 and 1.0, respectively, with the terms with Hermite polynomials all chosen to have zero coefficients except  $d_0 = 0.6$ . Thus the maximum velocity occurs at  $x = 0$ , where  $f_g = A + d_0 = 1.35$ . Such a velocity distribution (one with the peak velocity between the ends) cannot be described with the original Tsien formulation.

A duct designed from this velocity distribution is shown in figure 5 together with some streamlines, and the wall velocity distribution is shown in figure 4. The radial variation of velocity is noticeable at the minimum, where the curvature is relatively large. This result may be compared with that of figure 3 for the contraction cone where the relatively small curvature at the minimum results in a nearly uniform flow there.

## CONCLUDING REMARKS

A method for generalizing the Tsien procedure of contraction-cone design has been presented. The class of design velocity distributions is enlarged in such a way that conditions far upstream and downstream are unchanged, and so that the derivatives required in the calculation can be obtained by a recurrence formula rather than by numerical dif-

ferentiation. The generalized method is no longer restricted to contraction cones but now permits the design of diffusers and converging-diverging ducts.

Langley Research Center,  
National Aeronautics and Space Administration,  
Hampton, Va., September 26, 1972.

## APPENDIX

### COMPUTER PROGRAM FOR LOW-SPEED DUCT DESIGN

A computer program has been developed which will calculate the wall contour for a subsonic duct. The program is written in the FORTRAN IV language for use on CDC 6000 series computers. Since it was desired to take an interactive approach to the problem, the program has been implemented on the LRC interactive graphics system using the CDC 250 Cathode Ray Tube (CRT). The program listing and a description of its input and output are presented in this appendix.

#### Description of Program

The program is basically divided into two parts. Part I of the program builds an  $I \times 4$  design table where the stream function  $\psi$ , the axial coordinate  $x$ , the radial coordinate  $r$ , and the number of derivative terms  $N$  are column vectors;  $I$  is the number of row entries. The program computes the value of the stream function at any point  $x, r$  or the value of  $r$  for an arbitrary value of  $\psi$  at some specified axial coordinate. By employing these two computations (each of which stores an entry in the design table), the user can determine the neighborhood of the desired solution and approximate the boundaries of its convergence.

Part II of the program computes the radial coordinates which agree with some specified range of the axial coordinates and a fixed value of the stream function (streamlines). In addition, it gives the corresponding velocity distribution in the duct and its axial and radial components. The streamlines are visually displayed on the CRT with a visual cue at the point where the velocity is no longer monotonically increasing. The plotting specifications are variable and may be input during program execution.

#### Subprogram Index

The following is an index of the subprograms called by this program and their sources. AUTHOR denotes routines written by the authors of this paper. CALCOMP indicates routines available as a part of the CalComp graphic output system. CRT indicates routines which are a part of the LRC interactive graphic system. LIBRARY denotes routines which are on the LRC computer complex system tape. The functions of the authors' routines are also given.

# APPENDIX – Continued

<u>Subprogram</u>	<u>Source</u>	<u>Function</u>
ABS	LIBRARY	
AXES	CALCOMP	
CALPLT	CALCOMP	
CDC250	CRT	
DAYTIM	LIBRARY	
DERIV	AUTHOR	Computes the derivatives of $f_g(x)$ , equation (6)
ENCODE	LIBRARY	
EXP	LIBRARY	
FACT	AUTHOR	Computes the factorial of an integer
FLOAT	LIBRARY	
FOFR	AUTHOR	Evaluates $\psi - f_g(x)$ for routine ITR2
FUNC	AUTHOR	Evaluates the integral in $f_g(x)$
IFIX	LIBRARY	
ITR2	LIBRARY	
LEROY	CALCOMP	
LINPLT	CALCOMP	
MESSAGE	CRT	
MGAUSS	LIBRARY	
NEXT	CRT	

# APPENDIX – Continued

<u>Subprogram</u>	<u>Source</u>	<u>Function</u>
NOTATE	CALCOMP	
PARAMS	CRT	
PNTPLT	CALCOMP	
RECIN	LIBRARY	
RECOUT	LIBRARY	
RVALUE	AUTHOR	Computes $r$ , velocities $u$ and $v$ , and $G$ for $\psi$ at $x$
SCREEN	CRT	
SIGN	LIBRARY	
SQRT	LIBRARY	
STREAM	AUTHOR	Computes $\psi$ at any point $x, r$

## Program Input

The first two cards should contain the velocity distribution function (free field). It will be printed as a part of the header on the first page of program output.

The next input block should contain the velocity distribution function parameters and the parameters used in the iterative method to determine the radius of the duct. These variables should be input under the FORTRAN IV Namelist format. A description of these variables and the corresponding names used by the source program are as follows:

<u>Name</u>	<u>Symbol</u>	<u>Description</u>
\$FPARAM		Name required by input routine
AG1		Lower bound on the neighborhood of $r$
AG2		Upper bound on the neighborhood of $r$
C2	$c^2$	Velocity distribution function parameter

# APPENDIX – Continued

<u>Name</u>	<u>Symbol</u>	<u>Description</u>
DELR		Initial size of the scanning interval $r_{i+1} = r_i + \text{DELR}$ If $r_i < r < r_{i+1}$ , $\text{DELR} = \text{DELR}/2$
D1	$d_1$	Velocity distribution function parameter (see eq. (6))
D2	$d_2$	Velocity distribution function parameter (see eq. (6))
EPS1	$\Sigma_1$	Relative error criterion for determining convergence. If $ r_i  > \Sigma_1$ , $\left  \frac{r_i - r_{i-1}}{r_1} \right  \leq \Sigma_1$ implies convergence
EPS2	$\Sigma_2$	Absolute error criterion for determining convergence. If $r_i \leq \Sigma_1$ , $ r_i - r_{i-1}  \leq \Sigma_2$ implies convergence
MAXIT		Maximum number of iterations to be used
NACC	N	Number of derivative terms to be used
V1	$f_{g,i}$	Desired initial velocity in the duct
V2	$f_{g,f}$	Desired final velocity in the duct
\$		Required by input routine

The next input section forms the basis for the design table. Each card should contain an axial coordinate (columns 11-20, F10.4) and a radial coordinate (columns 21-30, F10.4). These coordinates should be chosen such that the stream function is specified throughout the entire field of interest. The value of the stream function is computed at these points and stored in the design table ordered on decreasing values of  $\psi$ .

The final input block is to be input at the CRT station. The variables in this block may be changed at any time during execution of the program affording interactive control over the program. By varying these parameters the user may take advantage of program options to (1) add and delete entries in the design table, (2) make limited changes to the velocity distribution function, and (3) vary the iteration scheme to achieve convergence.

# APPENDIX – Continued

<u>Name</u>	<u>Symbol</u>	<u>Description</u>
AG1		*
AG2		*
A1	A	Velocity distribution function parameter (see eq. (3))
A2	$2\sqrt{2} cB$	Velocity distribution function parameter
C2		*
DELR		*
DPSI		Increment from PSIMIN to PSIMAX
DX		Increment from XMIN to XMAX
D1		*
D2		*
EPS1		*
EPS2		*
GDIST		Length of Y-axis for velocity plot (in.)
GDV		Y-axis scale for velocity plot (units/in.)
GMAX		Maximum velocity computed
GMIN		Minimum velocity computed
GOR		Y-axis origin for velocity plot
I		Row number in design table



# APPENDIX – Continued

<u>Name</u>	<u>Symbol</u>	<u>Description</u>
IP1		Printing control for part I of program
IP2		Printing control for part II of program
MAXIT		*
NACC		*
PSI	$\psi$	*
PSIMAX		Maximum streamline to be computed
PSIMIN		Minimum streamline to be computed
R	r	*
RDIST		Length of Y-axis for radial plot (in.)
RDV		Y-axis scale for radial plot (units/in.)
RMAX		Maximum radius computed
RMIN		Minimum radius computed
ROR		Y-axis origin for radial plot
V1		*
V2		*
X	x	*
XDIST		Length of X-axis (in.)
XDV		X-axis scale (units/in.)
XMAX		Maximum value of x for which $\psi$ is computed

## APPENDIX – Continued

<u>Name</u>	<u>Symbol</u>	<u>Description</u>
XMIN		Minimum value of $x$ for which $\psi$ is computed
XOR		X-axis origin

### NOTE:

The starred (\*) variables are defined previously in the appendix.

A sample input follows:

$$F(X) = A1 + A2 * I(\text{SQRT}(2\text{PI}) * E^{**}(-C^{**2} * X^{**2}))DX + E^{**} - (X^{**2}) * (D1 * H0 + D2 * H1)$$

$$I = \text{INTEGRAL FROM 0 TO X}$$

$$\text{\$FPARAM AG1} = 0.0, \text{AG2} = 1.0, \text{C2} = 1.0, \text{DELR} = 0.1, \text{D1} = 0.0, \text{D2} = 0.1, \text{EPS1} = 1.E - 6,$$

$$\text{EPS2} = 1.E - 6, \text{MAXIT} = 200, \text{NACC} = 10, \text{V1} = 0.133, \text{V2} = 1.0\$$$

1.0	1.1
1.0	.9
0.0	1.0
-1.0	.9
-1.0	0.0
1.0	.7
1.0	.6
1.0	.4
-1.0	.7
-1.0	.6

### Program Output

On the first page of printed output, the velocity distribution function, its parameters, and the design table are printed.

On the following pages, the radial distribution is shown for  $\psi = \text{PSIMIN}$  to  $\psi = \text{PSIMAX}$  incremented by  $\text{DPSI}$  over an axial range of  $X = \text{XMIN}$  to  $X = \text{XMAX}$  incremented by  $\text{DX}$ . The resultant velocity  $G$  and its axial  $u$  and radial  $v$  components are also included.

The plotted output included the radial distribution curves, the velocity distribution curves, and the centerline velocity curve. They are displayed on the CRT during program execution with the capability of saving them for post-processing on the Calcomp plotter. The plot format is similar to that of the figures shown in the main body of the paper.

Following is the printed output which corresponds to the input previously presented. Streamlines are shown for  $\psi = 0.003, 0.006, 0.009, 0.012$ , and  $0.013$ . The centerline

velocity distribution is shown at  $\psi = 0.0$ . The proposed wall contour is streamline  $\psi = 0.013$ . Finally, the source program listing is presented.

# APPENDIX - Continued

CONTRACTION CONE DESIGN TABLE										DATE	04/18/72
VELOCITY DISTRIBUTION FUNCTION										F(X)=A1+A2*I(SQRT(2P1))*E**-(C**2*X**2)DX + E**X**2*(D1*H0 + D2*H1 )	
I = INTEGRAL FROM 0 TO X											
INIT. VEL.=	.1330	FINAL VEL.=	1.0000	A1=	.5665	A2=	1.2261	C**2=	1.00		
D1= 0.0000D2= .1000											
I	PSI	X	R	N							
1	.65341	1.00000	1.10000	10							
2	.42800	1.00000	.90000	10							
3	.28325	0.00000	1.00000	10							
4	.25399	1.00000	.70000	10							
5	.18511	1.00000	.60000	10							
6	.08125	1.00000	.40000	10							
7	.05000	-1.20000	-999.00000	10							
8	.04000	-1.20000	.94307	10							
9	.03592	-4.00000	.73491	10							
10	.03206	-1.00000	1.10000	10							
11	.03087	-1.00000	.90000	10							
12	.03000	-1.20000	.79327	10							
13	.02700	4.00000	.23238	10							
14	.02359	-1.00000	.70000	10							
15	.02016	1.00000	.20000	10							
16	.01883	-1.00000	.60000	10							
17	.01300	1.20000	.15974	20							
18	.01300	1.20000	.15974	15							
19	.01300	1.20000	.15974	13							
20	.01300	1.20000	.15974	11							
21	.01300	1.20000	.15974	10							
22	.01300	-1.20000	.49403	20							
23	.01300	-1.20000	.49403	15							
24	.01300	-1.20000	.49403	10							
25	.00939	-1.00000	.40000	10							
26	.00503	1.00000	.10000	10							
27	.00250	-1.00000	.20000	10							
28	.00063	-1.00000	.10000	10							
29	0.00000	0.00000	0.00000	10							
30	0.00000	1.00000	0.00000	10							
31	0.00000	-1.00000	0.00000	10							

## APPENDIX - Continued

R AND G DISTRIBUTION FOR CURVE 1										DATE
PSI =	0.000000	TO	0.000000	X =	-1.200000	TO	1.200000	N =	10	
INIT. VEL. =	.1330	FINAL VEL. =	1.0000	A1 =	.5665	A2 =	1.2261	C**2 =	1.0000	
		D1 =	0.0000	D2 =	.1000	PLOT NO.	2			
PT	X	R	U	V	G					
1	-1.200000	0.000000	.115016	0.000000	.115016					
2	-1.120000	0.000000	.118182	0.000000	.118182					
3	-1.040000	0.000000	.123752	0.000000	.123752					
4	-.960000	0.000000	.132286	0.000000	.132286					
5	-.880000	0.000000	.144339	0.000000	.144339					
6	-.800000	0.000000	.160432	0.000000	.160432					
7	-.720000	0.000000	.181016	0.000000	.181016					
8	-.640000	0.000000	.206426	0.000000	.206426					
9	-.560000	0.000000	.226854	0.000000	.236854					
10	-.480000	0.000000	.272313	0.000000	.272313					
11	-.400000	0.000000	.312620	0.000000	.312620					
12	-.320000	0.000000	.357383	0.000000	.357383					
13	-.240000	0.000000	.406006	0.000000	.406006					
14	-.160000	0.000000	.457707	0.000000	.457707					
15	-.080000	0.000000	.511553	0.000000	.511553					
16	.000000	0.000000	.566500	0.000000	.566500					
17	.080000	0.000000	.621447	0.000000	.621447					
18	.160000	0.000000	.675293	0.000000	.675293					
19	.240000	0.000000	.726994	0.000000	.726994					
20	.320000	0.000000	.775617	0.000000	.775617					
21	.400000	0.000000	.820380	0.000000	.820380					
22	.480000	0.000000	.860687	0.000000	.860687					
23	.560000	0.000000	.896146	0.000000	.896146					
24	.640000	0.000000	.926574	0.000000	.926574					
25	.720000	0.000000	.951984	0.000000	.951984					
26	.800000	0.000000	.972568	0.000000	.972568					
27	.880000	0.000000	.988661	0.000000	.988661					
28	.960000	0.000000	1.000714	0.000000	1.000714					
29	1.040000	0.000000	1.009248	0.000000	1.009248					
30	1.120000	0.000000	1.014818	0.000000	1.014818					
31	1.200000	0.000000	1.017984	0.000000	1.017984					

# APPENDIX - Continued

C

DATE

1

R AND G DISTRIBUTION FOR CURVE

TO

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# APPENDIX - Continued

R AND G DISTRIBUTION FOR CURVE 2										DATE	0
PSI = .006000											
INIT. VEL.= .1330											
FINAL VEL.= 1.0000											
DI= 0.0000											
PT											
X											
R											
U											
V											
G											
A1= .5665											
A2= 1.2261											
C**2= 1.0000											
N= 10											
T0											
X= -1.200000											
T0											
1.200000											
PLOT NO. 1											
1											
1.07393											
.108554											
.112568											
.120332											
.132549											
.149637											
.171771											
.198992											
.231256											
.268434											
.310270											
.356347											
.406071											
.458676											
.513245											
.568753											
.624117											
.678253											
.730131											
.778830											
.823582											
.863803											
.899113											
.929339											
.954508											
.974821											
.990628											
1.002389											
1.010634											
1.015929											
1.018842											

# APPENDIX - Continued

0

DATE

3

R AND G DISTRIBUTION FOR CURVE

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TO

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TO

1.200000

TO

-1.200000

X=

.5665

A1=

1.0000

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.009000

INIT. VEL.= .1330 FINAL VEL.= 1.0000 A1= .5665 A2= 1.2261 C\*\*2= 1.0000 N= 10

D1= 0.0000

D2= .1000

D3=

D4=

D5=

D6=

D7=

D8=

D9=

D10=

D11=

D12=

D13=

D14=

D15=

D16=

D17=

D18=

D19=

PT	X	R	U	V	G
1	-1.200000	.406027	.103549	-.001090	.103555
2	-1.120000	.403321	.103244	-.006144	.103427
3	-1.040000	.356189	.105612	-.012686	.106372
4	-.960000	.384037	.111722	-.020452	.113579
5	-.880000	.367172	.122528	-.028909	.125892
6	-.800000	.346805	.138678	-.037398	.143632
7	-.720000	.324588	.160464	-.045322	.166741
8	-.640000	.302072	.187910	-.052254	.195040
9	-.560000	.280397	.220867	-.057952	.228344
10	-.480000	.260254	.259067	-.062313	.266455
11	-.400000	.241977	.302116	-.065319	.309096
12	-.320000	.225664	.349485	-.067005	.355850
13	-.240000	.211270	.400495	-.067438	.406133
14	-.160000	.198675	.454320	-.066708	.459191
15	-.080000	.187723	.510004	-.064921	.514119
16	.000000	.178253	.566500	-.062201	.569905
17	.080000	.170104	.622715	-.058682	.625474
18	.160000	.163128	.677562	-.054510	.679751
19	.240000	.157189	.730015	-.049837	.731714
20	.320000	.152166	.779161	-.044817	.780449
21	.400000	.147952	.824242	-.039605	.825193
22	.480000	.144448	.864687	-.034350	.865369
23	.560000	.141568	.900129	-.029188	.900602
24	.640000	.139235	.930411	-.024243	.930727
25	.720000	.137377	.955572	-.019619	.955773
26	.800000	.135929	.975829	-.015398	.975950
27	.880000	.134833	.991545	-.011641	.991613
28	.960000	.134033	1.003191	-.008384	1.003226
29	1.040000	.133480	1.011310	-.005639	1.011326
30	1.120000	.133127	1.016477	-.003398	1.016483
31	1.200000	.132932	1.019267	-.001634	1.019268

## APPENDIX - Continued

R AND G DISTRIBUTION FOR CURVE 4										DATE	0
PSI =		.003000	TO	.012000	X=	-1.200000	TO	1.200000	N= 10		
INIT. VEL.=		.1330	FINAL VEL.=	1.0000	AL=	.5665	A2=	1.2261	C**2=	1.0000	
			DI=	0.0000	D2=	.1000	PLOT NO.	1			
PT	X	R	U	V	G						
1	-1.200000	.473172	.059754	.000634	.099756						
2	-1.120000	.471501	.057968	-.005067	.098099						
3	-1.040000	.464383	.058875	-.012724	.099690						
4	-.560000	.450723	.103838	-.022057	.106155						
5	-.880000	.430732	.114070	-.032366	.118573						
6	-.800000	.406059	.130289	-.042732	.137118						
7	-.720000	.379047	.152666	-.052337	.161388						
8	-.640000	.351812	.181023	-.060650	.190912						
9	-.560000	.325807	.215036	-.067404	.225353						
10	-.480000	.301837	.254317	-.072514	.264453						
11	-.400000	.280242	.298402	-.075995	.307927						
12	-.320000	.261075	.346724	-.077912	.355370						
13	-.240000	.244238	.398586	-.078362	.406216						
14	-.160000	.229554	.452154	-.077458	.459727						
15	-.080000	.216820	.509473	-.075332	.515013						
16	.000000	.205829	.566500	-.072128	.571073						
17	.080000	.196385	.623146	-.068006	.626845						
18	.160000	.188311	.678330	-.063133	.681262						
19	.240000	.181443	.721035	-.057687	.733308						
20	.320000	.175640	.780356	-.051847	.782076						
21	.400000	.170773	.825542	-.045790	.826811						
22	.480000	.166729	.866032	-.039689	.866941						
23	.560000	.163409	.901467	-.033701	.902097						
24	.640000	.160719	.921698	-.027969	.932117						
25	.720000	.158579	.956774	-.022612	.957041						
26	.800000	.156914	.976920	-.017727	.977081						
27	.880000	.155654	.992508	-.013381	.992598						
28	.960000	.154736	1.004017	-.009616	1.004063						
29	1.040000	.154103	1.011997	-.006446	1.012017						
30	1.120000	.153700	1.017029	-.003862	1.017036						
31	1.200000	.153480	1.019692	-.001829	1.019693						

.012000



# APPENDIX - Continued

0

DATE  
1.200000

1

R AND C DISTRIBUTION FOR CURVE

T0

1.0000

C\*2=

X=

A2=

A1=

T0

FINAL VEL.=

PSI =

.013000

N= 10

1.0000

1.2261

A2=

A1=

T0

FINAL VEL.=

PSI =

PT	X	R	U	V	G
1	-1.200000	.494033	.058499	.001352	.098509
2	-1.120000	.492865	.056175	-.004516	.096281
3	-1.040000	.485923	.056534	-.012509	.097342
4	-.560000	.471882	.101060	-.022356	.103503
5	-.880000	.450883	.111075	-.033294	.115958
6	-.800000	.424748	.127329	-.044300	.134815
7	-.720000	.396100	.149935	-.054472	.159523
8	-.640000	.367278	.178632	-.063237	.189495
9	-.560000	.335845	.213028	-.070329	.224338
10	-.480000	.314635	.252692	-.075674	.263780
11	-.400000	.291979	.297139	-.079299	.307538
12	-.320000	.271913	.345789	-.081284	.355214
13	-.240000	.254311	.397942	-.081734	.406249
14	-.160000	.238578	.452762	-.080771	.459910
15	-.080000	.225693	.509295	-.078536	.515315
16	.000000	.214233	.566500	-.075180	.571467
17	.080000	.204392	.623290	-.070368	.627306
18	.160000	.195581	.678587	-.065777	.681768
19	.240000	.188820	.721377	-.060091	.733841
20	.320000	.182788	.760756	-.053997	.782621
21	.400000	.177723	.825977	-.047680	.827352
22	.480000	.173515	.866482	-.041318	.867466
23	.560000	.170060	.901914	-.035076	.902596
24	.640000	.167263	.932128	-.029102	.932582
25	.720000	.165037	.957175	-.023521	.957464
26	.800000	.163306	.977284	-.018432	.977458
27	.880000	.161997	.992829	-.013906	.992927
28	.960000	.161044	1.004292	-.009986	1.004342
29	1.040000	.160386	1.012225	-.006687	1.012247
30	1.120000	.159569	1.017212	-.003998	1.017220
31	1.200000	.158742	1.019833	-.001884	1.019835

# APPENDIX - Continued

```
PROGRAM CNCONF (INPUT=1001,OUTPUT=1001,TAPE5=INPUT,TAPE6=OUTPUT,TAP
1E8)
```

C  
C  
C

## LOW SPEED DUCT DESIGN

```
DIMENSION PSIA(100), A(100), RA(100), MSG(10), TONE(8), XPLOT(500
1), YPLOT(500), NAC(100)
DIMENSION ORG(2), DV(2), DIST(2), JRCD(2)
DIMENSION DATE(2), FCT(8,2)
EQUIVALENCE (ROR,ORG(1)), (GOR,ORG(2)), (RDV,DV(1)), (GDV,DV(2)),
1(RDIST,DIST(1)), (GDIST,DIST(2))
COMMON /YD1/ DELR, EPS1, EPS2, MAXIT
COMMON /YD2/ NACC, PSI, X, R, U, V, G
COMMON /YD3/ A1, A2, C2, D1, D2
COMMON /YD4/ AG1, AG2
NAMELIST /FPARAM/ AG1, AG2, C2, DELR, D1, D2, EPS1, EPS2,
1 MAXIT, NACC, V1, V2
```

C  
C

## PROGRAM INITIALIZATION

```
CALL CDC250
CALL LEROY
CALL SCREFN (1.0,1.0,0.8)
S2=SQRT(2.0)
MNA=100
MPT=500
IP1=IP2=0
JNK1=0$JNK2=-1
LPLT=0
CALL DAYTIM (DATE)
READ 110, FCT
110 FORMAT (8A10)
READ(5,FPARAM)
```

C

```
CALL PARAMS
CALL PARAMS (3LPSI,PSI)
CALL PARAMS (1LX,X,1LR,R,1LI,I)
CALL PARAMS (4LDEL,DEL,5LMAXIT,MAXIT)
CALL PARAMS (4LEPS1,EPS1,4LEPS2,EPS2)
CALL PARAMS (2LA1,A1,2LA2,A2)
CALL PARAMS (4LNACC,NACC)
CALL PARAMS (3LAG1,AG1,3LAG2,AG2)
CALL PARAMS (3LIP1,IP1,3LIP2,IP2)
CALL PARAMS (2LV1,V1,2LV2,V2,2LC2,C2)
CALL PARAMS (2LD1,D1,2LD2,D2)
CALL MESSAGE (1.36H INSERT INITIAL VALUES FOR PSI EDIT,36)
CALL MESSAGE (1.25H ANY FN KEY WILL CONTINUE,25)
CALL NEXT (KEY)
J3=1
GO TO 510
120 CONTINUE
```

C

# APPENDIX - Continued

```

C          PART I
C      GENERATE INITIAL PSI DISTRIBUTION TABLE
      NA=0
130  READ 140, X,R
      IF (EOF,5) 180, 150
140  FORMAT (10X,2F10.4)
150  NA=NA+1
      IF (NA.LE.MNA) GO TO 170
      PRINT 160, MNA,NA
160  FORMAT (39H0MAXIMUM INITIAL PSI DIMENSION EXCEEDED,2I10)
      GO TO 130
C          COMPUTE      PSI
170  CALL STREAM
      PSIA(NA)=PSI$A(NA)=X+RA(NA)=R
      NAC(NA)=NACC
      GO TO 130
180  IF (NA.GT.MNA) NA=MNA
      J1=27
      ENCODE (J1,19,MESG) NA
190  FORMAT (1X,15,21H INITIAL PSI COMPUTED)
      CALL MESSAGE (1,MESG,1)
C
C
C      ORDER      INITIAL      PSI      TABLE      ( DESCENDING )
C      J3=NA-1
      DO 210 J1=1,J3
      J2=J1+1
      J4=J2
      IF (PSIA(J5).LT. PSIA(J4)) J5=J4
200  CONTINUE
      IF (J5.EQ.J1) GO TO 210
      SAV=PSIA(J1)$PSIA(J1)=PSIA(J5)$PSIA(J5)=SAV
      SAV=A(J1)$A(J1)=A(J5)$A(J5)=SAV
      SAV=RA(J1)$RA(J1)=RA(J5)$RA(J5)=SAV
      SAV=NAC(J1)$NAC(J1)=NAC(J5)$NAC(J5)=SAV
210  CONTINUE
C
C      DISPLAY INITIAL      PSI      TABLE
220  JRT=1
230  J2=20
      J5=50
      DO 260 J1=1,NA,J2
      J3=J1+J2-1
      IF (J3.GT.NA) J3=NA
      DO 250 J4=J1,J3
      ENCODE (J5,24,MESG) J4,PSIA(J4),A(J4),RA(J4),NAC(J4)
240  FORMAT (3H I=,12,5H PSI=,F13.6,3H X=,F8.4,3H R=,F8.4,3H N=,12)
      CALL MESSAGE (1,MESG,15)
250  CONTINUE
      CALL MESSAGE (3,33H ANY FN KEY WILL CONTINUE DISPLAY,33)
      CALL NEXT (KEY)
260  CONTINUE
C

```

# APPENDIX - Continued

```

C      EDIT      INITIAL      PSI      TABLE
C
CALL MESSAGE (1,25H END OF PSI RANGE DISPLAY,25)
GO TO (270,620), JRT
270 CALL MESSAGE (1,24H BEGIN EDIT RANGE OF PSI,24)
CALL MESSAGE (1,27H VARIABLES ARE X, R, I,27)
280 CALL MESSAGE (1,37H FN KEY 1 WILL COMPUTE PSI AT X AND R,37)
CALL MESSAGE (1,36H FN KEY 2 WILL INSERT PSI, X, AND R,36)
CALL MESSAGE (1,23H FN KEY 3 WILL DELETE I,23)
CALL MESSAGE (1,39H FN KEY 4 WILL DISPLAY PSI,X,AND R AT I,39)
CALL MESSAGE (1,32H FN KEY 5 WILL DISPLAY PSI RANGE,32)
CALL MESSAGE (1,36H FN KEY 6 WILL END EDIT AND CONTINUE,36)
CALL MESSAGE (1,37H FN KEY 7 WILL COMPUTE R AT PSI AND X,37)
CALL MESSAGE (1,41H FN KEY 8 SIMPLE TRANSFER TO PLOT ROUTINE,41)
CALL MESSAGE (1,38H FN KEY 9 WILL DELETE ENTIRE TABLE,38)
CALL MESSAGE (1,33H FN KEY 10 WILL COMPUTE A1, A2,33)
CALL MESSAGE (1,38H ANY OTHER FN KEY WILL DISPLAY OPTIONS,38)

C
CALL NEXT (KEY)
IF (KEY.EQ.1) GO TO 290
IF (KEY.EQ.2) GO TO 310
IF (KEY.EQ.3) GO TO 400
IF (KEY.EQ.4) GO TO 430
IF (KEY.EQ.5) GO TO 220
IF (KEY.EQ.6) GO TO 540
IF (KEY.EQ.7) GO TO 440
IF (KEY.EQ.8) GO TO 620
IF (KEY.EQ.9) GO TO 490
IF (KEY.EQ.10) GO TO 500
GO TO 280

C
C      COMPUTE      PSI
290 CALL STREAM
ENCODE (50,300,MESG) PSI,X,R,NACC
300 FORMAT (5H PSI=.F16.6,3H X=.F8.4,3H R=.F8.4,3H N=.I4)
CALL MESSAGE (1,MESG,50)
GO TO 280

C
C      INSERT      PSI      IN      TABLE
310 IF (NA.EQ.MNA) GO TO 390
IF (PSI.LT.PSIA(1)) GO TO 320
J1=1
GO TO 340
320 DO 330 J1=2,NA
IF ((PSI.LE.PSIA(J1-1)).AND.(PSI.GE.PSIA(J1))) GO TO 340
330 CONTINUE
J1=NA+1
GO TO 360
340 DO 350 J2=J1,NA

```

# APPENDIX - Continued

```

J3=NA-J2+J1
PSIA(J3+1)=PSIA(J3)%A(J3+1)=A(J3)%RA(J3+1)=RA(J3)
NAC(J3+1)=NAC(J3)
350 CONTINUE
360 PSIA(J1)=PSIA(J1)%RA(J1)=X%RA(J1)=R
NAC(J1)=NACC
NA=NA+1
370 ENCODE (7R,38A,MESG) NA,J1,NAC(J1),PSIA(J1),A(J1),RA(J1)
380 FORMAT (9H TOTAL I=,I4,3H I=,I4,3H N=,I3,4X,5H PSI=,F16.6,4H X=,F
19.4,4H R=,F9.4)
CALL MESSAGE (1,MESG,30)
CALL MESSAGE (1,MESG(4),47)
GO TO 280
390 CALL MESSAGE (4,23H MAX I HAS BEEN REACHED,23)
GO TO 280
C
C      DELETE ENTRY I IN PSI TABLE
400 DO 410 J2=I,NA
PSIA(J2)=PSIA(J2+1)
A(J2)=A(J2+1)
RA(J2)=RA(J2+1)
NAC(J2)=NAC(J2+1)
410 CONTINUE
NA=NA-1
ENCODE (30,420,MESG) NA,I
420 FORMAT (9H TOTAL I=,I5,18,8H DELETED)
CALL MESSAGE (1,MESG,30)
GO TO 280
C
430 J1=I
GO TO 370
C
C      COMPUTE R FOR PSI AT X
440 CALL PVALUE (ICODE)
ENCODE (50,450,MESG) PSI,X
450 FORMAT (5H PSI=,F16.8,5H X=,F16.8)
CALL MESSAGE (1,MESG,42)
ENCODE (50,460,MESG) R,G
460 FORMAT (3H R=,F16.8,5H G=,F16.8)
CALL MESSAGE (1,MESG,40)
ENCODE (50,470,MESG) U,V
470 FORMAT (3H U=,F16.8,6H V=,F16.8)
CALL MESSAGE (1,MESG,41)
ENCODE (50,480,MESG) NACC,ICODE
480 FORMAT (3H N=,J2,12H ERROR CODE=,I3)
CALL MESSAGE (1,MESG,20)
CALL MESSAGE (1,25H ANY FN KEY WILL CONTINUE,25)
CALL NEXT (KEY)
GO TO 280
490 NA=0$PSIA(1)=PSIA(2)=9.E10
CALL MESSAGE (1,14H TABLE DELETED,14)
GO TO 280
C
500 J3=2
GO TO 510

```

# APPENDIX - Continued

```

C
C      COMPUTE      FUNCTION      PARAMETERS      A1      A2
C
510  C2=ARS(C2)
      A1=0.5*(V1+V2)
      A2=S2*SORT(C2)*(V2-V1)
      ENCODE (100,520,MESG) V1,V2,C2,A1,A2
520  FORMAT (12H INIT. VEL.=,F8.4,12H FINAL VEL.=,F8.4,4H C2=,F10.6,6X,
14H A1=,F16.8,4H A2=,F16.8)
      CALL MESSAGE (1,MESG,40)
      CALL MESSAGE (1,MESG(5),20)
      CALL MESSAGE (1,MESG(7),40)
      ENCODE (34,530,MESG) D1,D2
530  FORMAT (4H D1=,F13.6,4H D2=,F13.6)
      CALL MESSAGE (1,MESG,34)
      GO TO (120,280), J3

C
C
C      END      INITIAL      PSI      EDIT
540  CALL MESSAGE (3,28H REPEAT FN KEY 6 TO END EDIT,28)
      CALL MESSAGE (1,38H ANY OTHER FN KEY WILL DISPLAY OPTIONS,38)
      CALL NEXT (KEY)
      IF (KEY.NE.6) GO TO 280
      IF (IPL.NE.0) GO TO 610

C
C      OUTPUT      INITIAL      PSI      TABLE
DO 600 J1=1,NA
      IF( MOD( J1-1, 35 ) .NE. 0 ) GO TO 595
      PRINT 550, DATE(1)
550  FORMAT(1H) //50X, *CONTRACTION CONE DESIGN TABLE*, 15X, *DATE*,
1 5X, A10)
      PRINT 560, FCT
560  FORMAT (/10X,30HVELOCITY DISTRIBUTION FUNCTION,5X,8A10/45X,8A10)
      PRINT 570, V1, V2, A1, A2, C2
570  FORMAT (/20X,11HINIT. VEL.=,F9.4,5X,11HFINAL VEL.=,F9.4,5X,3HA1=,F
19.4,5X,3HA2=,F9.4,5X,5HC**2=,F5.2)
      PRINT 571,D1, D2
571  FORMAT(53X, *D1=*, F8.4, * D2=*, F8.4)
      PRINT 580
580  FORMAT (/32X,1HI,17X,3HPSI,19X,1HX,19X,1HR,5X,1HN)
595  CONTINUE
      PRINT 590, J1,PSIA(J1),A(J1),RA(J1),NAC(J1)
590  FORMAT (28X,15.3F20.5,16)
600  CONTINUE
610  CONTINUE
C
C

```

# APPENDIX - Continued

C	SET-UP	PART PLOT	II PARAMETERS
C	CALL PARAMS (4LXMIN,XMIN,2LDX,DX,4LXMAX,XMAX)		
C	CALL PARAMS (4LPSIMIN,PSIMIN,4LDPSI,DPSI,6LPSIMAX,PSIMAX)		
C	CALL PARAMS (3LROR,ROR,3LRDV,RDV,5LRDIST,RDIST)		
	CALL PARAMS (3LGOR,GOR,3LGDV,GDV,5LGDIST,GDIST)		
	CALL PARAMS (3LXOR,XOR,3LXDV,XDV,5LXDIST,XDIST)		
	CALL PARAMS (4LRMIN,PMIN,4LRMAX,RMAX)		
	CALL PARAMS (4LGMIN,GMIN,4LGMAX,GMAX)		
C	XMIN=-4.0%DX=0.4%XMAX=4.0 PSIMIN=.027%DPSI=1.0%PSIMAX=.027 IB=8 JDATA=JPS=JGS=0 CALL CALPLT (0.0,0.0,-3) TMAJ=1.0\$TMIN=0.1 JXPCD=1HX%XHGT=4.0/15.0\$JNX=-1 XDIST=10.0\$RDIST=10.0\$GDIST=10.0 JBOD(1)=1HR\$JBOD(2)=1HG\$JN=+1 JSYM=0\$JSIZE=1\$PY=0.1 MCURVE=11		
C	620 CALL MESSAGE (1.32H FN KEY 1 WILL DISPLAY PSI RANGE,32) CALL MESSAGE (1.27H FN KEY 2 WILL COMPUTE DATA,27) CALL MESSAGE (1.46H VARIABLES ARE XMIN,DX,XMAX,PSIMIN,DPSI,PSIMAX,4 16) CALL MESSAGE (1.37H FN KEY 3 WILL SCALE PSI DISTRIBUTION,37) CALL MESSAGE (1.42H VARIABLES ARE XOR,XDV,XDIST,ROR,RDV,RDIST,42) CALL MESSAGE (1.37H FN KEY 4 WILL PLOT PSI DISTRIBUTION,37) CALL MESSAGE (1.35H FN KEY 5 WILL SCALE G DISTRIBUTION,35) CALL MESSAGE (1.31H VARIABLES ARE GOR,GDV,GDIST,31) CALL MESSAGE (1.35H FN KEY 6 WILL PLOT G DISTRIBUTION,35) CALL MESSAGE (1.44H FN KEY 7 WILL DISPLAY NON-MONOTONE VELOCITY,44) CALL MESSAGE (1.26H FN KEY 8 WILL END PROGRAM,26) CALL MESSAGE (1.39H FN KEY 9 WILL RETURN TO PSI RANGE EDIT,39) CALL MESSAGE (1.25H FN KEY 10 WILL NORMALIZE,25) CALL MESSAGE (1.38H ANY OTHER FN KEY WILL DISPLAY OPTIONS,38) CALL NEXT (KEY) IF (KEY.EQ.1) GO TO 630 IF (KEY.EQ.2) GO TO 640 IF (KEY.EQ.3) GO TO 810 IF (KEY.EQ.4) GO TO 930 IF (KEY.EQ.5) GO TO 1090 IF (KEY.EQ.6) GO TO 930 IF (KEY.EQ.7) GO TO 1120 IF (KEY.EQ.8) GO TO 1170 IF (KEY.EQ.9) GO TO 270 IF (KEY.EQ.10) GO TO 850 GO TO 620		
C			

# APPENDIX - Continued

```

C
C      DISPLAY      INITIAL      PSI      TABLE
630  JRT=2
      GO TO 230
C
C      COMPUTE      RADIAL      DISTRIBUTION
640  RCURVE=(PSIMAX-PSIMIN)/DPSI
      JNK1=JNK1+1
      LPLT=LPLT+1
C      CHECK      FOR      MAXIMUM      NUMBER      OF      CURVES
      IF (RCURVE.LE.FLOAT(MCURVE-1)) GO TO 660
      ENCODE (37,65,MESG) RCURVE,MCURVE
650  FORMAT (2X,F12.5,11H MORE THAN ,15.7H CURVES)
      CALL MESSAGE (4,MESG,37)
      GO TO 620
660  RPT=(XMAX-XMIN)/DX
C      CHECK      FOR      MAXIMUM      NUMBER      OF      POINTS
      IF (RPT.LE.FLOAT(MPT-1)) GO TO 680
      ENCODE (37,67,MESG) RPT,MPT
670  FORMAT (2X,F12.5,11H MORE THAN ,15.7H POINTS)
      CALL MESSAGE (4,MESG,37)
      GO TO 620
680  ICURVE=IFIX(RCURVE+1.5)
      NPT=IFIX(RPT+1.5)
      REWIND 18 $ JTONE=0
      RMAX=GMAX=-1.F0
      RMIN=GMIN=1.F0
      PSI=PSIMIN
C
C
      DO 790 J2=1,ICURVE
      GTONE=-1.F9
      IEOF=0$J3=-1
      X=XMIN
      ICODE=1
C
      DO 780 J1=1,NPT
C      COMPUTE      RADIUS
      CALL RVALUE (ICODE)
      IF (ICODE.EQ.0) DR=R
      CALL RECOIT (18,1,IEOF,J2,J1,PSI,X,R,U,V,G)
      IF (JTONE.NE.0) GO TO 700
C      CHECK      FOR      NON-MONOTONE      VELOCITY
      IF (G.GT.GTONE) GO TO 690
      TONE(1)=J2*TONE(2)=J1*TONE(3)=PSI*TONE(4)=X
      TONE(5)=R*TONE(6)=U*TONE(7)=V*TONE(8)=G
      JTONE=1
      GO TO 700
690  GTONE=G
700  CONTINUE
C      CHECK      FOR      MINIMUM      AND      MAXIMUM      YPLOT      VALUES

```



# APPENDIX - Continued

```

IF (R.LT.PMIN) RMIN=P
IF (R.GT.RMAX) RMAX=P
IF (G.LT.GMIN) GMIN=G
IF (G.GT.GMAX) GMAX=G
IF (IP2.NE.0) GO TO 770
J3=J3+1
C      OUTPUT      CURVE      J2
      IF( MOD( J3, 35 ) .NE. 0 ) GO TO 765
      PRINT 710, J2, DATE(), PSIMIN, PSIMAX, XMIN, XMAX
710   FORMAT (1H1//47X,34H R AND G DISTRIBUTION FOR CURVE .I3,20X,4HDA
      ITE,5X,A10//20X,6HPSI = ,F14.6,5X,2HT0.F14.6,10X,3HX= ,F14.6,5X,2HT
      20,F14.6)
      PRINT 720, PSI
720   FORMAT (5H0PSI=,F14.6)
      PRINT 730, V1, V2, A1, A2, C2, NACC
730   FORMAT (/8X,11HINIT. VEL.=,F8.4,5X,11HFINAL VEL.=,F8.4,5X,3HA1=,F8
      1.4,5X,3HA2=,F8.4,5X,5HC**2=,F8.4,5X,2HN=,I3)
      PRINT 740, D1, D2, LPLT
740   FORMAT (40X,3HD1=,F8.4,5X,3HD2=,F8.4,5X,8HPLOT NO.,I5)
      PRINT 750
750   FORMAT (/13X,2HPT,14X,1HX,14X,1HR,14X,1HU,14X,1HV,14X,1HG)
765   CONTINUE
      PRINT 760, J1,X,R,U,V,G
760   FORMAT (I15,5F15.6)
770   CONTINUE
C
      X=X+DX
      IF (X.GT.XMAX) X=XMAX
780   CONTINUE
C
      PSI=PSI+DPSI
      IF (PSI.GT.PSIMAX) PSI=PSIMAX
790   CONTINUE
C
C      DISPLAY      MINIMUM      AND      MAXIMUM      PLOT      VALUES
C
      ENCODE (80,80,MESG) RMIN,RMAX,GMIN,GMAX
800   FORMAT (6H RMIN=,F14.6,6H RMAX=,F14.6,6H GMIN=,F14.6,6H GMAX=,F14.
      16)
      CALL MESSAGE (1,16H DATA COMPUTED,16)
      CALL MESSAGE (1,MESG,40)
      CALL MESSAGE (1,MESG(5),40)
      JDATA=1
      GO TO 620
C
C
810   IF (JDATA.NE.0) GO TO 820
      CALL MESSAGE (2,29HCANNOT SCALE NO DATA COMPUTED,29)
      GO TO 620
C
C      COMPUTE      X      AND      R      SCALES

```

# APPENDIX - Continued

```

820  XOR=XMIN
      XDV=(XMAX-XMIN)/XDIST
      ROR=RMIN
      RDV=(RMAX-RMIN)/RDIST
      ENCODE (36.83^,MSG) XOR,XDV
830  FORMAT (5H XOR=,F12.5,7H   XDV=,F12.5)
      ENCODE (36.84^,MSG(6) )ROR,RDV
840  FORMAT (5H ROD=,F12.5,7H   RDV=,F12.5)
      CALL MESSAGE (1,MSG,36)
      CALL MESSAGE (1,MSG(6),36)
      JRS=1
      GO TO 620

C
C      NORMALIZE   LAST   MONOTONE   STREAM   LINE
850  JPLT=1
      IF (JNK1.NE.JNK2) GO TO 920
      DO 900 J1=1,NPT
      XPLT(J1)=XPLT(J1)/YPLT(NPT)
      YPLT(J1)=YPLT(J1)/YPLT(NPT)
      IF (MOD(J1-1,35).NE.0) GO TO 880
      PRINT 860, DATE(1)
860  FORMAT (1H1//27X,46HNORMALIZED CURVE FOR LAST MONOTONE STREAM LINE
1,10X,4HDATE,5X,A10)
      PRINT 720, PST
      PRINT 870
870  FORMAT (/33X,2HP(,19X,1HX,19X,1H*)
880  PRINT 890, J1,XPLT(1),YPLT(1)
890  FORMAT (25X,110,2F20.5)
900  CONTINUE
C
      ENCODE (80.91^,MSG) XPLT(1),XPLT(NPT),YPLT(NPT),YPLT(1)
910  FORMAT (4H X1=,F13.6,4H X2=,F13.6,6X,4H R1=,F13.6,4H R2=,F13.6)
      CALL MESSAGE (1,MSG,40)
      CALL MESSAGE (1,MSG(5),34)
      CALL MESSAGE (1,36H INPUT SCALE FACTORS PRESS ANY KEY ,36)
      CALL NEXT (KEY1)
      JNK2=JNK1
920  CONTINUE
      GO TO 950

C      READ      PLOT      DATA      JPLT=1, RPLT, JPLT=2,GPLT
C
930  JPLT=KEY/5+1
      IF ((JPLT.EQ.1).AND.(JRS.EQ.0)) GO TO 940
      IF ((JPLT.EQ.2).AND.(JRS.EQ.0)) GO TO 940
      GO TO 950
940  CALL MESSAGE (1,39H CANNOT PLOT. DATA HAS NOT BEEN SCALED,39)
      GO TO 620

C
950  CALL AXES (0,0,0,0,0,XDIST,XOR,XDV,TMAJ,TMIN,JXRCO,XHGT,JNX)
      CALL AXFS (0,0,0,0,90.0,DIST(JPLT),ORG(JPLT),DV(JPLT),TMAJ,TMIN,JR
1CD(JPLT),XHGT,JN)

```

# APPENDIX - Continued

```

REWIND 18
DO 990 J2=1,1CURVE
IF ( KEY .EQ. 10 ) GO TO 970
DO 960 J1=1,NPT
CALL RECIPI (I,1,IC,JCV,JPT,PSI,X,R,U,V,G)
XPLOT(J1)=X
YPLOT(J1)=R
IF (JPLT.FO.2) YPLOT(J1)=G
960 CONTINUE
C
970 XPLOT(NPT+1)=XOR$XPLOT(NPT+2)=XDV
YPLOT(NPT+1)=DVG(JPLT)$YPLOT(NPT+2)=DV(JPLT)
C PLOT DATA
CALL LINPLT (XPLOT,YPLOT,NPT+1,JSYM,J2,JSIZE,0)
C
C NOTATE PLOT
J3=17
ENCODE (J3,980,MESG) PSI
980 FORMAT (4HPSI=,F13.6)
PHT=0.1
PY=FLOAT(J2-1)*(PHT+.2)
PX1=2.5
CALL NOTATE (-PX1,PY,PHT,MESG,0.0,J3)
PA=(6.0/7.0)*FLOAT(J3)*PHT+0.14-PX1
PY=PY+0.04
CALL PNTPLT (PX,PY,J2,1)
IF ( KEY .EQ. 10 ) GO TO 991
990 CONTINUE
991 CONTINUE
ENCODE (15,1000,MESG) V1
1000 FORMAT (3HV1=,F13.6)
PY=DIST(JPLT)-PHT
CALL NOTATE (-PX1,PY,PHT,MESG,0.0,16)
ENCODE (15,1010,MESG) V2
1010 FORMAT (3HV2=,F13.6)
PY=PY-2.0*PHT
CALL NOTATE (-PX1,PY,PHT,MESG,0.0,16)
ENCODE (15,1020,MESG) C2
1020 FORMAT (5HC**2=,F13.6)
PY=PY-2.0*PHT
CALL NOTATE (-PX1,PY,PHT,MESG,0.0,18)
ENCODE (15,1030,MESG) D1
1030 FORMAT (3HD1=,F13.6)
PY=PY-2.0*PHT
CALL NOTATE (-PX1,PY,PHT,MESG,0.0,16)
ENCODE (15,1040,MESG) D2
1040 FORMAT (3HD2=,F13.6)
PY=PY-2.0*PHT
CALL NOTATE (-PX1,PY,PHT,MESG,0.0,16)
ENCODE (15,1050,MESG) A1
1050 FORMAT (3HA1=,F13.6)

```

# APPENDIX - Continued

```

PY=PY-2.0*PHT
CALL NOTATE (-PX1,PY,PHT,MESG,0.0,16)
ENCODE (16,1060,MESG) A2
1060  FORMAT (7H A2=,F13.6)
PY=PY-2.0*PHT
CALL NOTATE (-PX1,PY,PHT,MESG,0.0,16)
ENCODE (14,1070,MESG) LPLT
1070  FORMAT (9HPLOT NO. ,I5)
PY=PY-2.0*PHT
CALL NOTATE (-PX1,PY,PHT,MESG,0.0,14)
C
IF (JTONE.EQ.3) GO TO 1080
IF (KEY.EQ.10) GO TO 1080
C   FLAG      NON-MONOTONE VELOCITY ON PLOT
PX=(TONE(4)-XOR)/XDV
PY=(TONE(3*JPLT+2)-ORG(JPLT))/OV(JPLT)
CALL PNTPLT (PX,PY,1),3)
1080  CALL CALPLT (14.0,0.0,-3)
GO TO 620
1090  IF (JDATA.NE.0) GO TO 1100
CALL MESSAGE (3,29H CANNOT SCALE,NO DATA COMPUTED,29)
GO TO 620
C   COMPUTE      G      SCALES
1100  GOR=GMIN
GDV=(GMAX-GMIN)/GDIST
ENCODE (36,1110,MESG) GOR,GDV
1110  FORMAT (5H GOR=,F12.5,7H GDV=,F12.5)
CALL MESSAGE (1,MESG,36)
JGS=1
GO TO 620
1120  IF (JTONE.NE.0) GO TO 1130
CALL MESSAGE (1,23H VELOCITY IS MONOTONE,23)
GO TO 620
C   DISPLAY      NON-MONOTONE VELOCITY
1130  ENCODE (43,1140,MESG) TONE(1),TONE(2)
1140  FORMAT (7H CURVE ,F3.0,5H PT,F4.0,22H NON-MONOTONE VELOCITY)
CALL MESSAGE (7,MESG,41)
ENCODE (50,1150,MESG) TONE(3),TONE(4),TONE(5)
1150  FORMAT (5H P1=,F12.5,5H X=,F12.5,4H R=,F12.5)
CALL MESSAGE (1,MESG,50)
ENCODE (50,1160,MESG) TONE(6),TONE(7),TONE(8)
1160  FORMAT (3H U=,F12.5,5H V=,F12.5,6H G=,F12.5)
CALL MESSAGE (1,MESG,50)
GO TO 620
C
C   NORMAL PROGRAM STOP
1170  CALL MESSAGE (4,31H REPEAT FN KEY R TO END PROGRAM,31)
CALL MESSAGE (4,38H ANY OTHER FN KEY WILL DISPLAY OPTIONS,38)
CALL NEXT (KEY)
IF (KEY.NE.8) GO TO 620
PRINT 1180

```

# APPENDIX - Continued

```

1180 FORMAT (25H1 NORMAL END OF JOB )
      STOP
      END
      SUBROUTINE STREAM
C
C      COMPUTE VALUE OF THE STREAM FUNCTION PSI AT X AND R
C      X = AXIAL COORDINATE
C      R = RADIAL COORDINATE
C
      COMMON /YD2/ NACC,PSI,X,R
C
      COF(J)=(-1.0)**(J-1)*R**(2*J)/(2.0**J2*FLOAT(J)*FACT(J-1)**2)
C
      PSI=0.0
      DO 10 J1=1,NACC
      J2=2*J1-2
      PSI=PSI+COF(J1)*DERIV(J2)
10    CONTINUE
      PSI=0.5*PSI
C
      RETURN
      END
      SUBROUTINE RVALUE (ICODE)
C
C      COMPUTE R, U, V, AND G FOR PSI AT X
C      G IS THE RESULTANT VELOCITY
C      U IS THE AXIAL COMPONENT
C      V IS THE RADIAL COMPONENT
C      USE INTERVAL-HALVING METHOD
C
      COMMON /YD1/ DELR,EPS1,EPS2,MAXIT
      COMMON /YD2/ NACC,PSI,X,R,U,V,G
      COMMON /YD4/ AG1,AG2
      EXTERNAL FOFR
      COF(J)=(-1.0)**(J-1)*R**J2/(2.0**(2*J-3)*FACT(J-1)**2)
      COFF(J)=(-1.0)**(J)*R**J3/(2.0**(2*J-2)*FLOAT(J)*FACT(J-1)**2)
C
      CALL ITR2 (R,AG1,AG2,DELR,FOFR,EPS1,EPS2,MAXIT,ICODE)
      IF (ICODE.EQ.0) GO TO 10
      R=U=V=G=-999.0
      RETURN
C
10    U=V=0.0
      DO 40 J1=1,NACC
      J2=2*J1-2
      J3=2*J1-1
C
      IF ((J2.NE.0).OR.(ABS(R).GT.1.E-12)) GO TO 20
      U=2.0*DERIV(J2)
      GO TO 30

```

# APPENDIX - Continued

```

20  CONTINUE
    U=U+COF(J1)*DERIV(J2)
30  CONTINUE
    V=V+COFF(J1)*DERIV(J3)
40  CONTINUE
    U=0.5*U
    V=0.5*V
C
C
    G=SQRT(U**2+V**2)
    RETURN
    END
    FUNCTION FACT (J)
C
C    FACTORIAL FUNCTION
    FACT=1.0
    IF (J.EQ.0) RETURN
    IF (J.EQ.1) RETURN
C
    DO 10 J1=2,J
    FACT=FACT*FLOAT(J1)
10  CONTINUE
    RETURN
    END
    FUNCTION FOFR (R)
C    EVALUATE FUNCTION FOR IT-2
    COMMON /YD2/ NACC,PSI,X,RR
C
    SAVI=PSI
    RR=R
    CALL STREAM
    FOFR=PSI
    PSI=SAVI
    FOFR=PSI-FOFR
    RETURN
    END
    FUNCTION DERIV (J)
    COMMON /YD2/ NACC,PSI,X
    COMMON /YD3/ A1,A2,C2,D1,D2
    DIMENSION HERM(50), HER(50), FOFX(1), ANS(1)
    EXTERNAL FUNC
C
C    COMPUTE JTH DERIVATIVE OF VELOCITY FUNCTION
    SR=SQRT(2.0*3.14159265)
    EX=EXP(-C2*X**2)/SR
    EX1=EXP(-X**2)
    HERM(1)=EX
    HERM(2)=-2.0*C2*X*HERM(1)
    HER(1)=1.0
    HER(2)=2.0*X
    HER(3)=4.0*X**2-2.0

```

# APPENDIX - Concluded

```

HER(4)=8.0*X**3-12.0*X
C
C
IF (J.NE.0) GO TO 20
RL1=0.0*RL2=X
IF (RL2.GT.RL1) GO TO 10
RL1=X*RL2=0.0
10 CONTINUE
CALL MGAUSS (PL1,RL2,10,ANS,FUNC,FOFX,1)
DERIV=A1+SIGN(1.0,X)*A2*ANS+EX1*(D1*HER(1)+D2*HER(2))
RETURN
C
20 IF (J.NE.1) GO TO 30
DERIV=A2*FX-EX1*(D1*HER(2)+D2*HER(3))
RETURN
C
30 IF (J.NE.2) GO TO 40
DERIV=-2.0*A2*C2*X*EX+EX1*(D1*HER(3)+D2*HER(4))
RETURN
C
40 HER(J+1)=2.0*X*HER(J)-2.0*FLOAT(J-1)*HER(J-1)
HER(J+2)=2.0*X*HER(J+1)-2.0*FLOAT(J)*HER(J)
C
IF (J.EQ.3) GO TO 50
HERM(J-1)=-2.0*C2*(X*HERM(J-2)+FLOAT(J-3)*HERM(J-3))
50 HERM(J)=-2.0*C2*(X*HERM(J-1)+FLOAT(J-2)*HERM(J-2))
S1=1.0
IF (MOD(J,2).NE.0) S1=-1.0
DERIV=A2*HERM(J)+S1*EX1*(D1*HER(J+1)+D2*HER(J+2))
RETURN
END
SUBROUTINE FUNC (X,FOFX)
DIMENSION FOFX(1)
COMMON /YD3/ A1,A2,C2
C EVALUATE VELOCITY FUNCTION FOR MGAUSS
SR=SQRT(2.0*3.14159265)
FOFX=EXP(-C2*X**2)/SR
RETURN
END

```

## REFERENCES

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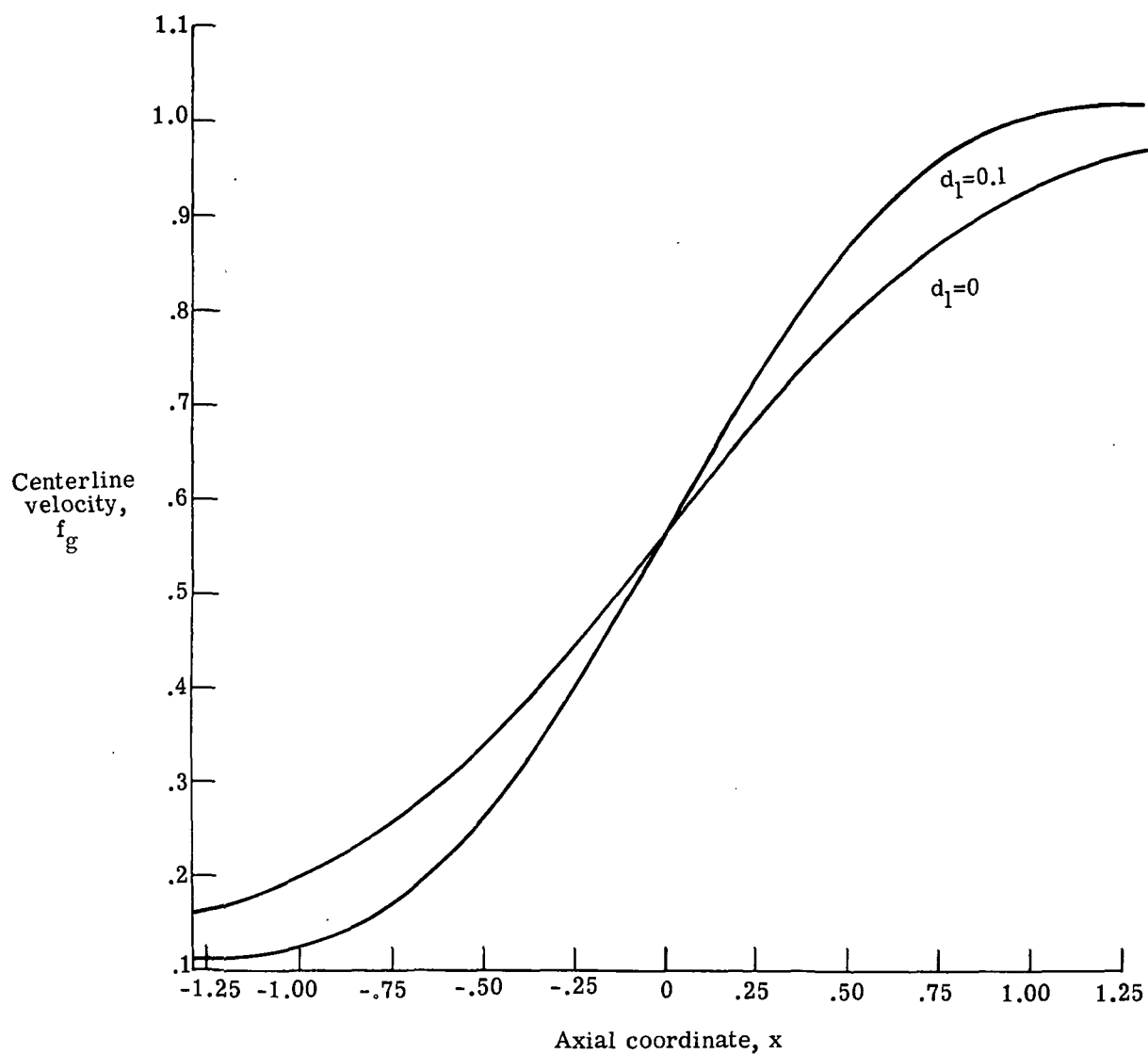


Figure 1.- Axial velocity used for contraction-cone design ( $d_1 = 0.1$ ) compared with that obtained with  $d_1 = 0$ . Nonzero parameters:  $A = 0.5665$ ;  $B = 0.4335$ ;  $c = 1$ .

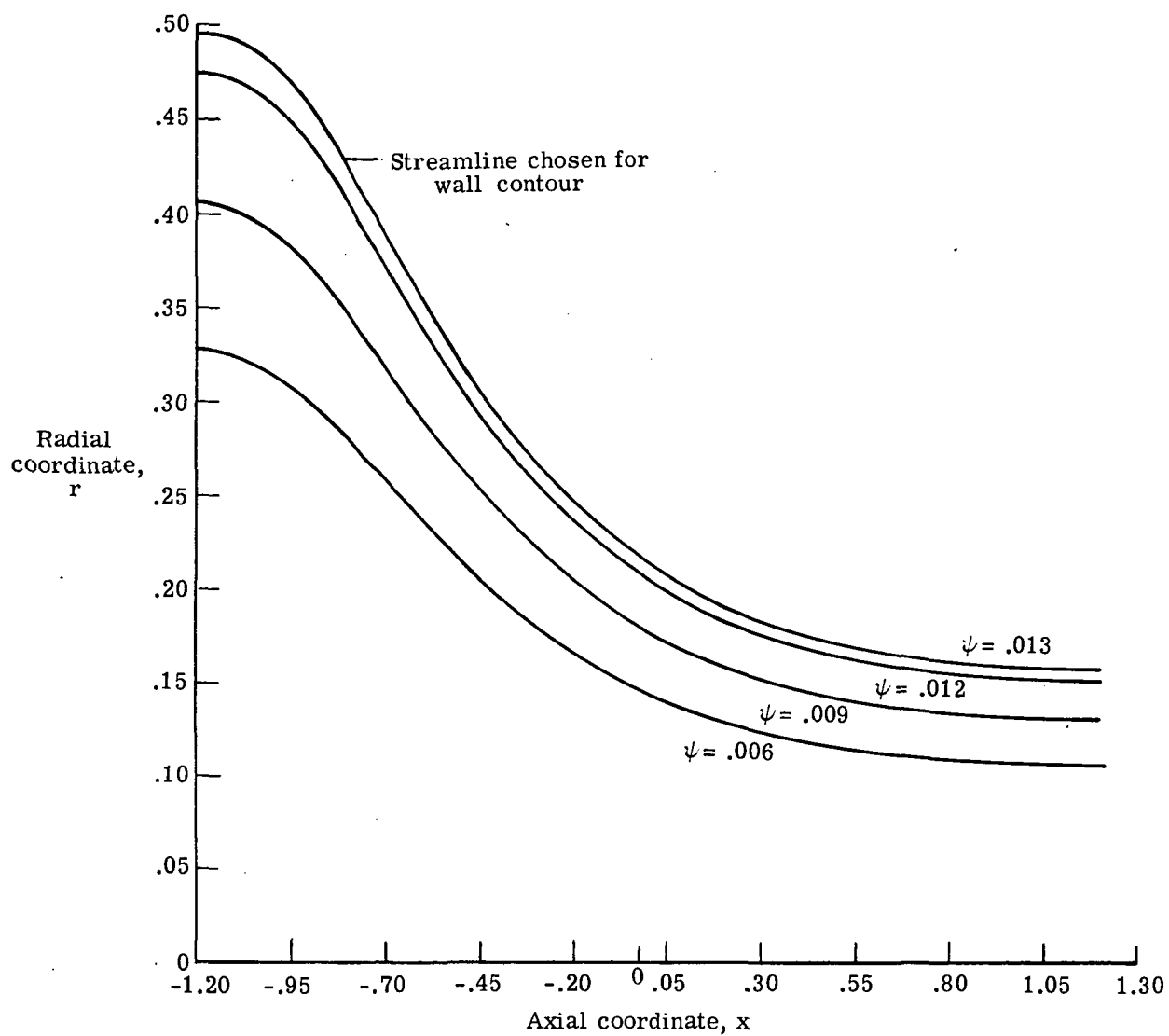


Figure 2.- Coordinates of wall contour and some streamlines  
for design velocity of figure 1.

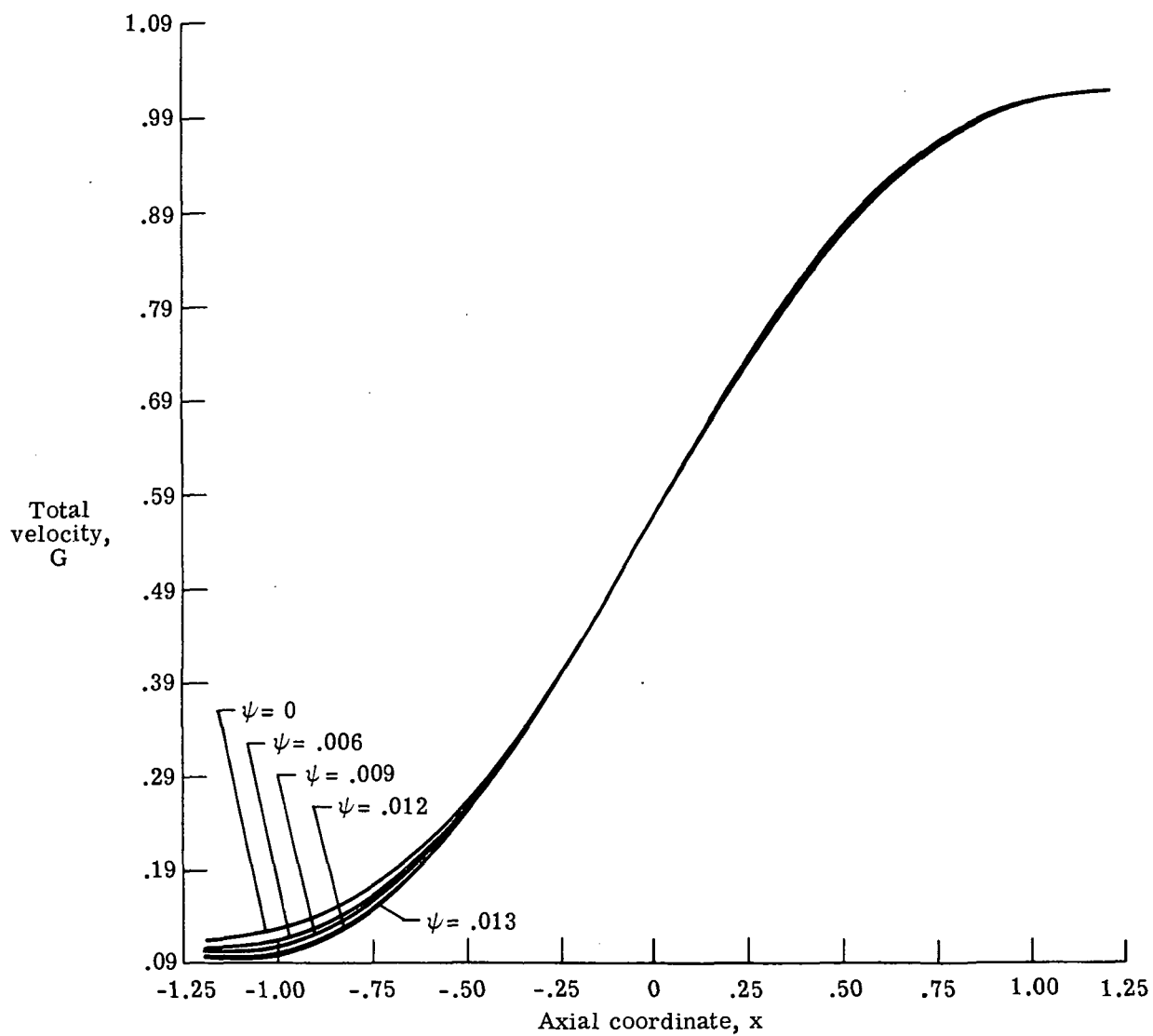


Figure 3.- Velocity distributions along centerline, wall, and streamlines of figure 2.

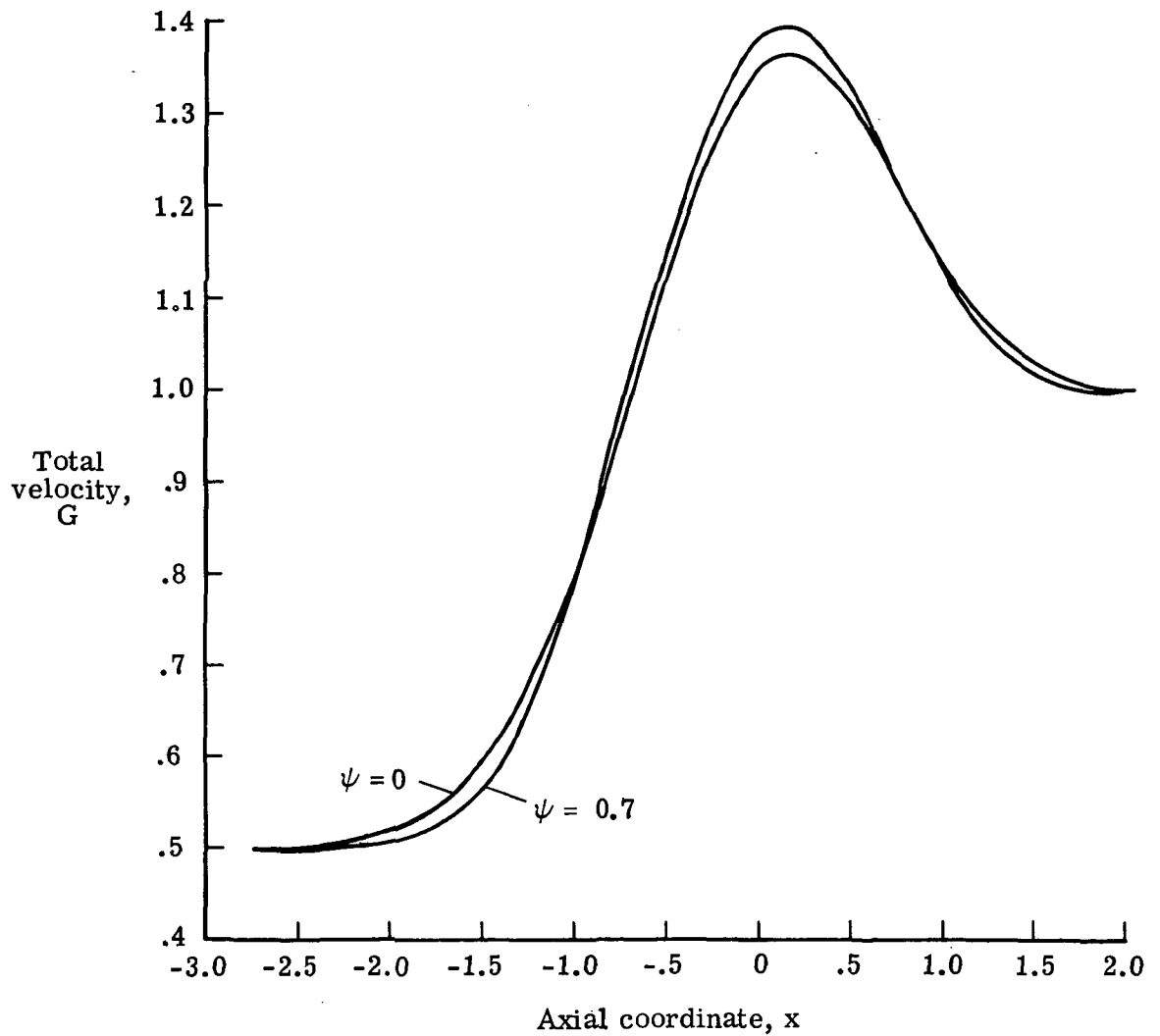


Figure 4.- Design (centerline) and wall velocity distribution for duct with an area minimum. Nonzero parameters:  $A = 0.75$ ;  $B = 0.25$ ;  $d_0 = 0.6$ ;  $c^2 = 0.5$ .

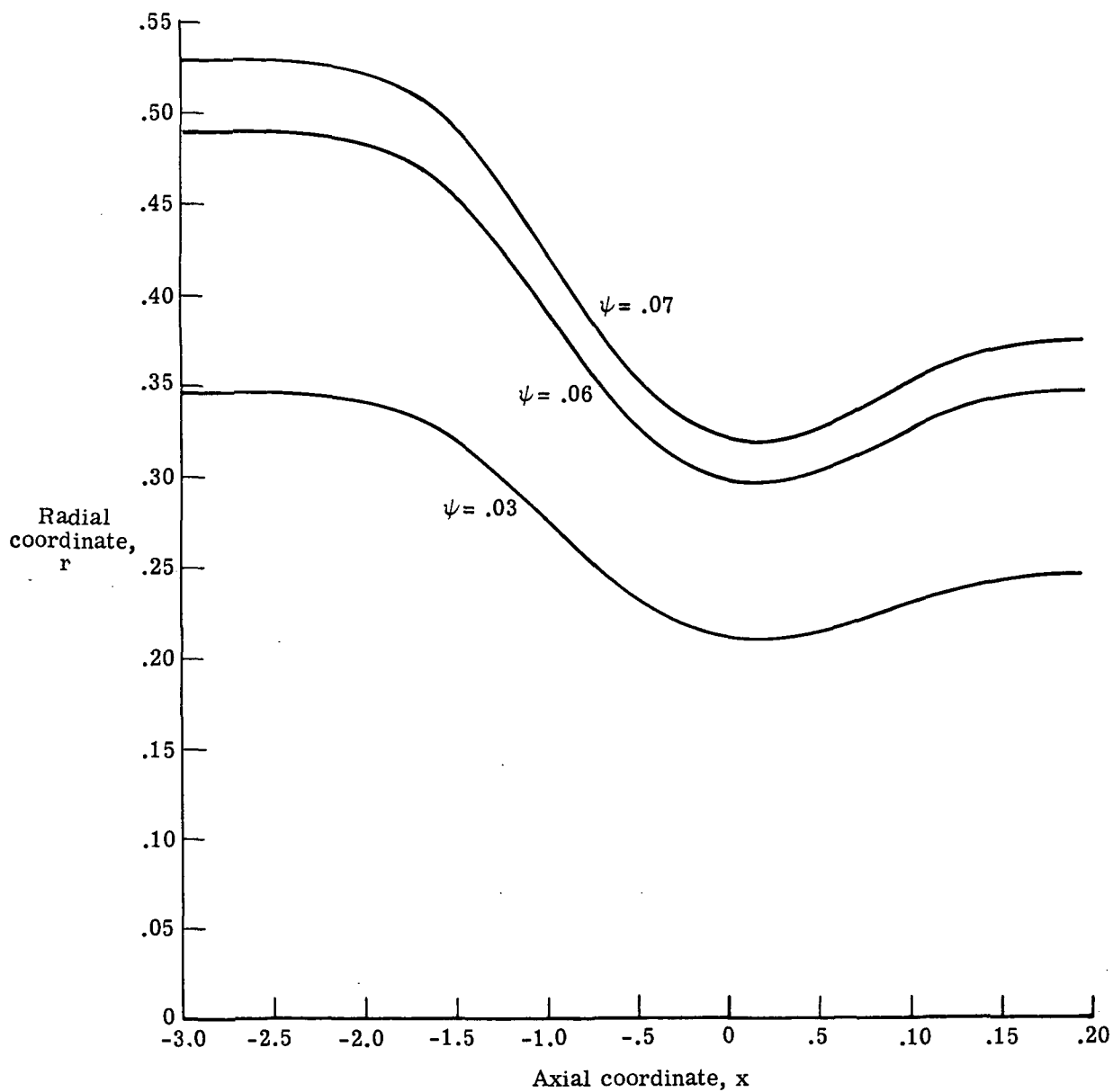


Figure 5.- Wall contour and some streamlines for the design velocity of figure 4.



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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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